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APPLICATION OF SPRING TABS TO ELEVATOR CONTROLS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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ADVANCE RESTRICTED REPORT

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APPLICATION OF SPRING TABS TO ELEVATOR CONTROLS

By William H. Phillips

SUMMARY

Equations are presented for calculating the stick-force characteristics obtained with a spring-tab type of elevator control. The main problems encountered in the design of a satisfactory elevator spring tab are to provide stick forces in the desired range, to maintain the force per g sufficiently constant throughout the speed range, to avoid undesirable "feel" of the control in ground handling, and to prevent flutter. Examples are presented to show the design features of spring tabs required to solve these problems for airplanes of various sizes. It appears possible to provide satisfactory elevator control-force characteristics over a large center-of-gravity range on airplanes weighing from about 16,000 to 300,000 pounds. On airplanes weighing less than 16,000 pounds, some difficulty may be encountered in obtaining sufficiently heavy stick forces for rapid movements of the control stick.

Some special tab designs, including geared and preloaded spring tabs, are discussed. The geared spring tab is shown to offer a means of obtaining satisfactory ground control without introducing excessive variation of force per g with speed.

By the use of spring tabs on elevators, the control forces may be made more closely predictable and the variation of stick-force characteristics among different airplanes of the same type may be greatly reduced. One of the principal objections to the use of spring tabs is the amount of weight required for mass balance to prevent flutter.

INTRODUCTION

Difficulties have been encountered in obtaining desirable control-force characteristics on large or

high-speed airplanes, because the hinge moments on the control surfaces must be very closely balanced and because slight changes in the hinge-moment parameters result in large changes in control forces. The advantages of spring tabs in overcoming these difficulties have been pointed out in reference 1 and other reports. It has been recognized, however, that the use of a spring tab on an elevator results in a decreasing value of the stick force per g normal acceleration with increasing speed that might be considered undesirable. An analysis is presented herein of the effects of spring tabs on elevator forces for airplanes of various sizes. The results indicate that an elevator equipped with a suitably designed spring tab may avoid any serious disadvantage from this effect and may still obtain the advantage of having the control forces predictable and relatively insensitive to variations in the elevator hinge-moment characteristics.

#### SYMBOLS

W	weight
b	span
S	wing area
c	chord
l	tail length
S <sub>T</sub>	tail area
$\left(\frac{dC_L}{da}\right)_w$	slope of lift curve of wing
ε	downwash angle
q	dynamic pressure
q <sub>T</sub>	dynamic pressure at tail
τ	elevator effectiveness factor $\left(\frac{\partial C_{LT}/\partial \delta_e}{\partial C_{LT}/\partial a_T}\right)$

$C_L$	lift coefficient
$V_s$	stalling speed
$I$	elevator moment of inertia
$K_1$	ratio of stick movement to elevator deflection, tab fixed; normally positive
$K_2$	ratio of stick movement to tab deflection, elevator fixed; normally negative
$K_3$	ratio of stick force to tab angle at zero airspeed, elevator fixed; normally positive
$H$	hinge moment
$C_h$	hinge-moment coefficient $\left( \frac{H}{qbc^2} \right)$
$\delta_e$	elevator deflection (positive down)
$\delta_t$	tab deflection (positive down)
$x_s$	stick movement (positive forward)
$F$	stick force (pull force positive)
$\alpha$	angle of attack of wing
$\alpha_T$	angle of attack of tail
$\rho$	mass density of air
$n$	normal acceleration in g units
$g$	acceleration of gravity (32.2 ft/sec <sup>2</sup> )
$x$	distance between center of gravity and stick- fixed neutral point in straight flight (positive when center of gravity is rearward)
$\left( \frac{dC_{h_e}}{d\alpha_T} \right)_{tf}$	variation of elevator hinge-moment coefficient with angle of attack of tail, measured with tab free

$\left(\frac{dC_{he}}{d\delta_e}\right)_{tf}$  variation of elevator hinge-moment coefficient with elevator angle, measured with tab free

d distance between tab mass-balance weight and tab hinge line

f distance between elevator hinge line and tab hinge line

$$A = \frac{W \left(1 - \frac{d\epsilon}{da}\right)}{\left(\frac{dC_L}{da}\right)_w S} + g \frac{\rho l}{2}$$

$$B = \frac{Wx}{\frac{\partial C_{LT}}{\partial \delta_e} \frac{q_T}{q} S_T l} - \frac{1}{\tau} g \frac{\rho l}{2}$$

Subscripts

T tail  
t tab  
e elevator

#### EQUATIONS FOR ELEVATOR FORCES

The method of deriving the equations for the elevator control force in maneuvers with a spring tab will be briefly outlined. These equations are similar to equations given in reference 2 but have been arranged to give a clearer physical significance to the various terms.

The change in elevator hinge moment caused by any change in angle of attack, elevator angle, or tab angle is given by the following formula:

$$\Delta H_e = \left( \Delta \alpha_T \frac{\partial C_{he}}{\partial \alpha_T} + \Delta \delta_e \frac{\partial C_{he}}{\partial \delta_e} + \Delta \delta_t \frac{\partial C_{he}}{\partial \delta_t} \right) q_T b e c_e^2 \quad (1)$$

The corresponding change in tab hinge moment is given by the expression

$$\Delta H_t = \left( \Delta a_T \frac{\partial C_{ht}}{\partial a_T} + \Delta \delta_e \frac{\partial C_{ht}}{\partial \delta_e} + \Delta \delta_t \frac{\partial C_{ht}}{\partial \delta_t} \right) q_T b_t c_t^2 \quad (2)$$

The change in elevator angle and the corresponding change in angle of attack at the tail - both of which enter into the calculation of the change in elevator hinge moment - may be derived for any type of maneuver. The change in tab angle required to insert in equation (1) depends on the particular linkage arrangement under consideration. The present discussion will consider the spring-tab arrangement shown in figure 1. For this arrangement, the relation between the stick force, the elevator hinge moment, and the tab hinge moment, when the system is in equilibrium, is given by the formula

$$\left. \begin{aligned} \Delta F &= \frac{\Delta H_e}{K_1} \\ &= \frac{\Delta H_t + \Delta \delta_t K_2 K_3}{K_2} \end{aligned} \right\} \quad (3)$$

in which the constants  $K_1$  and  $K_2$  are the gearing ratios between the stick and elevator and between the stick and tab, respectively, defined by the formula

$$x_s = K_1 \delta_e + K_2 \delta_t \quad (4)$$

and the constant  $K_3$  is the stiffness of the spring. This spring constant for an unpreloaded spring tab is defined in terms of the stick force required at zero airspeed to deflect the tab with the elevator fixed; thus,

$$F = K_3 \delta_t \quad (5)$$

By simultaneous solutions of equations (1), (2), and (3), the stick force required in any maneuver for an elevator equipped with an unpreloaded spring tab may be derived. The elevator force required to produce a given change in acceleration in gradual pull-ups is used as a criterion of the elevator control characteristics. In a pull-up,

the change in angle of attack at the tail is given by the formula

$$\Delta \alpha_T = \left[ \frac{W \left( 1 - \frac{d\epsilon}{d\alpha} \right)}{\left( \frac{dC_L}{d\alpha} \right)_w q S} + \frac{g_2^p l}{q} \right] (n - 1) \quad (6)$$

and the change in elevator angle required is given by the formula

$$\Delta \delta_e = \left[ \frac{W x}{\frac{\partial C_{LT}}{\partial \delta_e} q_T S_T l} - \frac{1}{\tau} \frac{g_2^p l}{q} \right] (n - 1) \quad (7)$$

In order to show the relation between the elevator forces required with a spring tab and the forces obtained with a conventional elevator, the equations for the force per  $g$  in a pull-up are derived first for an elevator without a tab, then for an elevator with a servotab, and finally for an elevator with a spring tab. In the case of a conventional elevator, the change in elevator hinge moment may be derived from equation (1). By use of the values for  $\Delta \alpha_T$  and  $\Delta \delta_e$  obtained from equations (6) and (7) and by setting  $\Delta \delta_t = 0$ , the force per  $g$  normal acceleration is found to be

$$\frac{\partial F}{\partial n} = -\frac{1}{K_1} \left[ A \frac{\partial C_{he}}{\partial \alpha_T} + B \frac{\partial C_{he}}{\partial \delta_e} \right] \frac{q_T b_e c_e^2}{q} \quad (8)$$

where

$$\left. \begin{aligned} A &= \frac{W \left( 1 - \frac{d\epsilon}{d\alpha} \right)}{\left( \frac{dC_L}{d\alpha} \right)_w S} + \frac{g_2^p l}{q} \\ B &= \frac{W x}{\frac{\partial C_{LT}}{\partial \delta_e} \frac{q_T}{q} S_T l} - \frac{1}{\tau} \frac{g_2^p l}{q} \end{aligned} \right\} \quad (9)$$

The second case considered is that of a servotab, which is defined as the system shown in figure 1 with the spring omitted. In this case, the stick force in a pull-up may be obtained from equations (1), (2), and (3) by setting the spring constant  $K_3$  equal to zero. The relation obtained for the force per  $g$  is

$$\frac{\partial F}{\partial n} = \frac{\frac{1}{K_1} \left[ A \left( \frac{\partial C_{he}}{\partial a_T} \right)_{tf} + B \left( \frac{\partial C_{he}}{\partial \delta_e} \right)_{tf} \right] \frac{q_T}{q} b_e c_e^2}{1 - \frac{K_2 \frac{\partial C_{he}}{\partial \delta_t} b_e c_e^2}{K_1 \frac{\partial C_{ht}}{\partial \delta_t} b_t c_t^2}} \quad (10)$$

This equation differs from that for the force without a tab in two ways. The first difference is that the terms  $\partial C_{he} / \partial a_T$  and  $\partial C_{he} / \partial \delta_e$  are replaced by the corresponding values which would be measured on the elevator with the tab free. These values for the tab-free condition are given by the expressions

$$\left. \begin{aligned} \left( \frac{\partial C_{he}}{\partial a_T} \right)_{tf} &= \frac{\partial C_{he}}{\partial a_T} - \frac{\frac{\partial C_{ht}}{\partial a_T} \frac{\partial C_{he}}{\partial \delta_t}}{\frac{\partial C_{ht}}{\partial \delta_t}} \\ \left( \frac{\partial C_{he}}{\partial \delta_e} \right)_{tf} &= \frac{\partial C_{he}}{\partial \delta_e} - \frac{\frac{\partial C_{ht}}{\partial \delta_e} \frac{\partial C_{he}}{\partial \delta_t}}{\frac{\partial C_{ht}}{\partial \delta_t}} \end{aligned} \right\} \quad (11)$$

If the tab does not have any floating tendencies, the values obtained with equations (11) are the same as those obtained for the elevator with the tab fixed. The second difference is that in the denominator a term is added which depends upon the ratio of the elevator dimensions to the tab dimensions, the ratio of the effectiveness of the tab to its aerodynamic hinge moment, and the ratio between the tab and elevator gearing constants. This added term, which in practical designs may range in value from five to several hundred, effectively



divides the elevator stick force that would be obtained without a tab by a large factor. The force per g for a servotab, like that for the elevator without a tab, is essentially independent of speed.

The force per g for an elevator equipped with an unpreloaded spring tab is found to be

$$\frac{\partial F}{\partial n} = \frac{\frac{1}{K_1} \left\{ A \left[ \left( \frac{dC_{he}}{da_T} \right)_{tf} + \frac{K_2 K_3 \frac{\partial C_{he}}{\partial a_T}}{\frac{\partial C_{ht}}{\partial \delta_t} q_T b_{tc} t^2} \right] + B \left[ \left( \frac{dC_{he}}{d\delta_e} \right)_{tf} + \frac{K_2 K_3 \frac{\partial C_{he}}{\partial \delta_e}}{\frac{\partial C_{ht}}{\partial \delta_t} q_T b_{tc} t^2} \right] \right\} \frac{q_T}{g} b_{ce}^2}{1 - \frac{K_2 \frac{\partial C_{he}}{\partial \delta_t} b_{ce}^2}{K_1 \frac{\partial C_{ht}}{\partial \delta_t} b_{tc} t^2} + \frac{K_2 K_3}{\frac{\partial C_{ht}}{\partial \delta_t} q_T b_{tc} t^2}} \quad (12)$$

Three terms are added when the tab-spring constant is taken into account. All three terms are seen to be of the same form and contain the dynamic pressure  $q_T$  in the denominator. At very low speeds, therefore, these three terms will be very large compared with any other terms in equation (12) and, in this case, the equation reduces to the form of equation (8), the force per g of the elevator without a spring tab. At very high speeds, the three added terms in equation (12) approach zero and the equation for force per g reduces to that derived for a servotab (equation (10)). The actual variation of force per g with speed for various values of the spring constant  $K_3$  is shown for a typical spring-tab installation in figure 2.

#### DESIGN PROBLEMS

The main problems that arise in connection with the design of a spring tab for an elevator are as follows:

- (a) To provide stick forces in the desired range
- (b) To maintain force per g sufficiently constant through the speed range

(c) To avoid undesirable "feel" of control for ground handling

(d) To prevent flutter

These four conditions will be shown to restrict the design characteristics of a satisfactory elevator spring tab to a rather narrow range for any particular type of airplane.

Some additional discussion may be necessary to clarify points (b) and (c). The force per g obtained with a servotab has been shown not to vary with speed. A servotab has been found to be undesirable, however, because the elevator does not follow movements of the stick smoothly when the airplane is on the ground or taxiing at low speed. The use of a spring tab provides a mechanical connection between the stick and the elevator and relieves this difficulty. One of the main problems in connection with the design of a spring tab is to avoid an undesirably large variation of force per g with speed in flight and still to provide a sufficiently rigid connection between the stick and the elevator to give control while the airplane is taxiing. The variation of force per g with speed in flight may be reduced to a small value by using a spring sufficiently weak that, in the normal-flight speed range, the control behaves essentially as a servotab. It is necessary to decide upon some criterion for the minimum value of spring stiffness required for control while the airplane is taxiing.

The response of the elevator to a sudden stick movement depends upon the elevator hinge moment that results from a unit stick deflection. If the elevator is held fixed, the variation of elevator hinge moment with stick deflection for an elevator equipped with a spring tab is given by the following equation:

$$\frac{\partial H_e}{\partial x_s} = \frac{-K_1 K_3}{K_2} + \frac{\frac{\partial C_{h_e}}{\partial \delta_t} q_T b_e c_e^2}{K_2} - \frac{K_1 \frac{\partial C_{h_t}}{\partial \delta_t} q_T b_t c_t^2}{K_2^2} \quad (13)$$

At zero speed the elevator hinge moment comes entirely from the spring but, as the speed increases, the

aerodynamic hinge moment due to tab deflection is added. The initial angular acceleration of the elevator, which occurs after a sudden stick movement, depends on the ratio of elevator hinge moment to stick deflection divided by the moment of inertia of the elevator about its hinge line. In flight tests of a small fighter airplane, the minimum value of spring stiffness required for satisfactory feel of the controls on the ground corresponded to the value (at zero airspeed)

$$\frac{1}{I} \frac{\partial H_e}{\partial x_s} = \frac{K_1 K_3}{K_2 I} = 200 \text{ foot-pounds per foot per slug-foot}^2$$

This value is, of course, many times smaller than the degree of rigidity present in a conventional control system but has nevertheless been shown to be satisfactory for the case of the small fighter airplane. For a large airplane, particularly one equipped with a tricycle landing gear, elevator control should not be required until speeds approaching the take-off speed are reached. In such a case, then, a lower value of the ratio might

be acceptable at zero airspeed. The value of  $\frac{1}{I} \frac{\partial H_e}{\partial x_s}$  should, however, be reasonably large at speeds approaching the take-off speed.

#### EXAMPLES

Design considerations.— In order to illustrate the application of spring tabs to elevator controls of airplanes of various sizes, the stick-force characteristics in maneuvers have been calculated for four airplanes ranging in size from a scout bomber to an airplane weighing 500,000 pounds, which represents about the largest type of airplane now being contemplated by aircraft designers. In each case, a practical spring-tab design has been arrived at that provides stick-force characteristics which satisfy the requirements of reference 3. These examples show what design features of a spring tab are required to obtain stick forces for maneuvering within the range required for each class of airplane and indicate also special problems that may arise in the design of spring tabs for aircraft of

particular sizes. The characteristics of the airplanes chosen as examples are given in table I. Certain factors that were considered in designing the spring tabs are as follows:

(a) The spring stiffness has been selected on the basis of providing satisfactory ground control by making the value of  $\frac{1}{I} \frac{\partial H_e}{\partial x_s}$  at zero airspeed equal to or greater than 200 foot-pounds per foot per slug-foot<sup>2</sup> except where otherwise noted.

(b) A reasonable degree of aerodynamic balance of the elevator, corresponding to a value of  $\frac{\partial C_{h_e}}{\partial \delta_e} = -0.002$  or  $-0.003$ , has been assumed so that large elevator deflections may be obtained without having the tab size or deflection exceed practical limits. The value of  $\frac{\partial C_{h_e}}{\partial \alpha_T} = 0$ , which has been used in all calculations, may be attained in practice by suitable choice of the elevator contours. Variation in the value of  $\frac{\partial C_{h_e}}{\partial \alpha_T}$  will not, however, alter the effects of the spring tab but will simply shift the stick-free neutral points in straight and turning flight by the same amount for a spring tab as for a conventional type of balance.

(c) The tab hinge-moment characteristics were assigned the representative values  $\frac{\partial C_{h_t}}{\partial \delta_t} = -0.003$  or  $-0.005$ ,  $\frac{\partial C_{h_t}}{\partial \delta_e} = 0$ , and  $\frac{\partial C_{h_t}}{\partial \alpha_T} = 0$ . By suitable modification of the tab design, considerable variation in these values may be obtained. The effects of such changes on the stick forces may be determined from formulas (11) and (12).

Scout bomber (weight, 16,000 lb).— The variation of force per g with speed and with center-of-gravity position for a scout bomber weighing 16,000 pounds is shown in figure 3. The desirable range of stick forces (shown by cross hatching in figures) is indicated in accordance

with the requirements of reference 3. A center-of-gravity range of 10 percent of the mean aerodynamic chord has been assumed.

The hypothetical curve of force per g at zero speed, which also represents the force per g throughout the speed range when a spring tab is not used, shows that a conventional elevator with the degree of balance used would give heavy stick forces and an excessive variation of force per g with center-of-gravity position. The assumed spring tab reduces the variation of force per g with center-of-gravity position to an acceptable amount. The variation of force per g with speed, for the spring stiffness chosen to give satisfactory ground control, also appears to be desirably small. Somewhat larger values of force per g are obtained near the minimum speed, but this fact is thought to be unimportant because the airplane stalls at low values of normal acceleration in this speed range. The stick forces were generally too low with a spring tab alone but have been raised to an acceptable value by the use of a small bobweight that requires a pull force of about three pounds on the stick.

Although the combination of spring tab and bobweight gives stick forces that satisfy the requirements, recent flight tests have shown that such an arrangement might be considered unsatisfactory to the pilots because of the lightness of the stick force required to make large rapid movements of the stick. This lightness, of course, results from the small effective value of  $\partial C_{He} / \partial \delta_e$ , which is necessary in order to obtain a small variation of force per g with center-of-gravity position. The requirement for light stick forces over such a large center-of-gravity range on an airplane of this type seems, in fact, to be incompatible with the pilot's desire for forces large enough to prevent inadvertent movements of the control stick.

The problem of providing sufficient heaviness of the control stick for quick movements (with the resultant undesirable variation of force per g with center-of-gravity position) when a spring tab is used may present some difficulties on an airplane as small as a scout bomber. The following possibilities are available for making the forces heavier:

- (a) To decrease  $K_2$ , the mechanical advantage of the stick over the tab
- (b) To increase the tab chord
- (c) To increase  $\partial C_{H_t} / \partial \delta_t$  by use of strips on the tab trailing edge
- (d) To reduce the amount of aerodynamic balance on the elevator

Of these possibilities, (a) and (b) may excessively increase the amount of mass balance required to prevent flutter, a subject that will be discussed in a later section of the paper. Only a limited advantage is gained by method (c). Method (d) will require the use of a larger tab to obtain large elevator deflections. By a combination of these methods, however, it appears practicable to obtain a sufficiently large centering tendency of the stick on an airplane of the scout-bomber

class. For a given value of  $\frac{1}{I} \frac{\partial H_e}{\partial x_s}$  at zero airspeed, changes (a), (b), and (c) give a favorable reduction in the variation of force per g with speed.

Satisfactory control feel might possibly be provided, even on an airplane that has no variation of force per g with center-of-gravity position, by suitable inertia weights or damping devices in the control system. Several systems for accomplishing this result have been proposed, but none has yet been tested in flight.

Medium bomber (weight, 50,000 lb)..- The stick-force characteristics of a medium bomber weighing 50,000 pounds with the assumed spring-tab design are shown in figure 4. The spring stiffness, chosen on the basis of ground control, provides a sufficiently small variation of force per g with speed. The stick forces lie within the desired limits. It is believed that the centering tendency of the control stick associated with these forces would be considered sufficiently large, although no tests have been made of an airplane of this size to verify this belief.

Heavy bomber (weight, 125,000 lb)..- The calculated stick-force characteristics of a heavy bomber (weight, 125,000 lb) are shown in figure 5. In order to obtain

stick forces within the desired range, a tab of rather narrow chord and an increased value of  $K_2$  (the mechanical advantage of the stick over the tab) have to be used. When these measures are adopted, it is no longer possible to meet the criterion for ground control

$\left( \frac{1}{I} \frac{\partial H_e}{\partial x_s} \right)$  at zero speed = 200 foot-pounds per foot per slug-foot<sup>2</sup>) and still maintain a sufficiently small variation of force per g with speed. Although the spring stiffness required to obtain the characteristics shown in figure 5 is greater than the stiffness used on the

smaller airplanes, the value of  $\frac{1}{I} \frac{\partial H_e}{\partial x_s}$  at zero speed is considerably reduced but reaches a value of 200 at a speed of 80 miles per hour. This condition would probably be acceptable, however, on a large airplane with a tricycle landing gear.

Airplane of 300,000 pounds weight.— The calculated stick-force characteristics of an airplane weighing approximately 300,000 pounds are shown in figure 6. On an airplane of this size, considerable care must be taken to balance aerodynamically both the elevator and the tab in order to obtain sufficiently light stick

forces. A very small value of  $\frac{1}{I} \frac{\partial H_e}{\partial x_s}$  at zero speed must also be accepted in order to avoid excessive variation of force per g with speed. The value of

$\frac{1}{I} \frac{\partial H_e}{\partial x_s}$  for this tab arrangement exceeds 200 at speeds above 102 miles per hour.

The stick forces on an airplane of this size depend rather critically on the elevator and tab hinge-moment characteristics. In view of the rather limited data available at present on the hinge-moment characteristics of tabs, special tests would undoubtedly be required to develop a design that provides the desired hinge-moment parameters. The degree of balance required is not so high that small variations in contours among different airplanes would cause excessive variations in the stick forces. It therefore appears that a spring tab may be used to provide satisfactory elevator control on an airplane of at least 300,000 pounds gross weight. The limiting size

of airplane that could be adequately controlled by this means is difficult to estimate, inasmuch as factors such as the response of the elevator to stick movements, rather than the magnitude of the stick forces, would probably set the upper limit on the size of airplane that could be controlled. The increasing importance of the elevator inertia on large airplanes is caused by the fact that the moment of inertia of the elevator tends to increase as approximately the fourth power of the linear dimension, whereas the aerodynamic hinge moments due to the tab vary as the cube of the linear dimension.

### DISCUSSION OF EXAMPLES

The ability of the spring tab to provide desirable stick-force characteristics over a large center-of-gravity range on airplanes weighing between about 16,000 and 300,000 pounds has been shown by the preceding examples. The lower limit on the size of airplane that can be controlled is determined by the requirement for a definite centering tendency of the control stick. The upper limit is not clearly defined but probably is set by the ability of the elevator to follow rapid stick movements.

One advantage of the spring-tab control is that any variation in the stick-force characteristics between airplanes of the same type, caused by slight differences in the contours of the elevators, would be much less for a spring-tab elevator than for an elevator equipped with a conventional type of balance such as a balancing tab or an inset hinge. This difference may be explained as follows: In order to obtain desirable stick forces with a conventional type of balance, the elevator hinge-moment parameters  $\partial C_{He}/\partial \delta_e$  and  $\partial C_{He}/\partial \alpha_T$  must be reduced to very small values. Variations of these parameters caused by slight differences in the elevator contours are likely to be of the same order of magnitude as the desired values. Such variations would cause changes in the stick-force characteristics of 100 percent or more. In the case of the spring tab, however, a high degree of balance of the elevator is not required. The stick forces are reduced to desirable values by the action of the tab. A properly designed spring tab has been shown to act essentially as a servotab at normal flight speeds. The formula for the force per g with a



servotab (equation (10)) shows that the force per g is reduced by a large factor in the denominator that depends on the tab and linkage characteristics. The effects of any variations in the values of  $\partial C_{H_e} / \partial a_T$  and  $\partial C_{H_e} / \partial \delta_e$  will be reduced by the same ratio. Inasmuch as this ratio varies from about 1:10 in the case of the scout bomber to 1:100 in the case of the 300,000-pound airplane, the spring tab should effectively eliminate any difficulties caused by variations in elevator hinge-moment parameters.

Errors in the predicted stick-force characteristics for a proposed spring-tab design, caused by failure to obtain the desired elevator hinge-moment characteristics, are likewise reduced by this ratio. As a result, the control characteristics of a spring-tab elevator should be more closely predictable than those of a conventional elevator, especially on a large airplane. This advantage is somewhat offset by the fact that the stick forces obtained with a spring tab depend on the hinge-moment parameters of the tab, as well as of the elevator. At present, information on the hinge-moment characteristics of tabs is not very complete.

The spring tab should provide an effective means of control in high-speed flight, especially as regards recovery from high Mach number dives, where the control forces on a conventional elevator may become excessive. It is known that trim tabs may be used to recover from dives, at least at the Mach numbers reached by present-day airplanes, but this procedure is known to be extremely dangerous because, when the airplane reaches lower altitudes and Mach numbers, excessive accelerations may be experienced before the trim tabs can be returned to neutral. The spring tab directly controlled by the stick should eliminate this difficulty. Furthermore, the stick forces with a spring tab would not be likely to become excessive in the pull-out. The effects of compressibility may in many cases be considered as a large rearward shift of the neutral point (of the order of 20 to 30 percent of the mean aerodynamic chord). Figures 3 to 6 show that such a shift would lead to excessive stick forces for recovery with a conventional elevator but to reasonable forces for a spring-tab control. In order to effect recovery, the elevator and tail would have to be built sufficiently strong to withstand the large loads imposed.

## PREVENTION OF FLUTTER

A theoretical investigation of the flutter of spring tabs is presented in reference 4 and the practical results are given in reference 5. These reports show that both the elevator and tab must be mass-balanced about their hinge lines and that the tab mass-balance weight must be placed closer to the tab hinge line than a certain distance defined by the relation

$$d = \frac{f}{1 - \frac{K_1}{K_2}} \quad (14)$$

In order to be most effective, the tab mass-balance weight should be placed about half this distance ahead of the tab hinge line. Equation (14) shows that, if the mechanical advantage of the stick over the tab  $K_2$  is reduced to a small value, the tab mass-balance weight must be placed so close to the tab hinge line that a prohibitively large weight may be required. Equation (4) indicates that  $K_1$  and  $K_2$  cannot be reduced simultaneously without unduly decreasing the stick travel.

A small value of the mechanical advantage of the stick over the tab has been shown to be advantageous on small airplanes in order to provide sufficiently large stick-force gradients and small variation of force per g with speed. An experimental investigation to determine the validity of equation (14) is, therefore, urgently required. Because of effects of flexibility in the control linkages, the applicability of equation (14) is open to some question in cases in which  $K_2$  is small. In some instances spring tabs without mass balance have been used without the occurrence of flutter. Special devices with a smaller penalty due to weight have also been proposed to prevent flutter.

## STICK-FORCE CHARACTERISTICS IN STRAIGHT FLIGHT

In figures 3 to 6, the rear limit of the assumed center-of-gravity range was taken as the stick-fixed (actually, elevator- and tab-fixed) neutral point in

straight flight. Because  $\frac{\partial C_{he}}{\partial a_T}$  was taken equal to zero, this point also represents the stick-free neutral point. For all center-of-gravity positions ahead of this point, the stick-force variation with speed will be stable and the gradient will be reduced by the spring tab in the same proportion as the maneuvering forces. The effects of changes in the hinge-moment parameters  $\frac{\partial C_{he}}{\partial \delta_e}$  and  $\frac{\partial C_{he}}{\partial a_T}$  and the effects of altitude on the neutral point and maneuver point may be shown to follow the same rules with a spring tab as with a conventional elevator.

### SPECIAL SPRING-TAB ARRANGEMENTS

The formulas set up for the stick forces obtained in maneuvers with a spring tab may be used to determine the characteristics of several special arrangements.

Tab controlled independently of elevator.- The mechanism for a tab controlled independently of elevator is shown diagrammatically in figure 7(a). This arrangement is a special case of the previously used system in which the elevator gearing constant  $K_1$  equals zero. The stick-force characteristics may be found from equations (12) and (13) by setting  $K_1$  equal to zero.

If  $K_1$  equals zero, the value of  $K_2$  must be large enough to require full stick travel for full tab deflection. For airplanes weighing about 50,000 pounds or less, a small value of  $K_2$  was required to provide sufficiently heavy stick forces. The tab controlled independently of elevator would therefore be considered satisfactory only on large airplanes. Formula (13) furthermore indicates that, when  $K_1 = 0$ , the elevator will not be constrained to follow stick movements at zero airspeed no matter how stiff a spring is used. The system of figure 7(a) will thus have no advantages over a servotab from the standpoint of ground control. The spring should therefore be omitted in order to avoid a force per g that varies with speed. This system is more likely than an ordinary spring tab to result in instability of the short-period oscillation of the airplane with stick fixed, because the stability of the elevator itself

with stick fixed is essentially the same as with stick free. As a result, the dynamic stability of the airplane with stick fixed is no greater than with stick free. With a conventional spring tab such as that shown in figure 1, on the other hand, the effective restoring moment on the elevator with stick fixed is greatly increased by the leading action of the tab, so that the stick-fixed dynamic stability of the airplane is close to the elevator-fixed value. The only benefit that appears to result from the use of the system of figure 7(a) is a possible reduction of stick forces on a very large airplane because of the increased allowable mechanical advantage of the stick over the tab. Use of this alternative does not appear to be necessary, however, for the largest airplane considered (300,000 pounds weight).

Geared spring tab.- The mechanism for a geared spring tab is shown diagrammatically in figure 7(b). This device differs from an ordinary spring tab in that, when the elevator is moved (at zero airspeed) with the stick free, the tab deflects with respect to the elevator in the same manner as a conventional geared tab or balancing tab. The stick-force characteristics for a geared spring tab may be calculated by means of the same equations as those derived for an ordinary spring tab, if certain substitutions are made for the hinge-moment parameters of the elevator. These substituted values may be interpreted physically as the hinge-moment parameters of an elevator equipped with an equivalent balancing tab, which is defined as a balancing tab that has the same gearing ratio as would be obtained on the geared spring tab with stick free at zero airspeed.

By means of a geared spring tab, the force per g at low airspeed may be reduced without decreasing the force per g at high speed and without reducing the response of the elevator to rapid stick movements on the ground. This device, in fact, presents the theoretical possibility of obtaining a force per g that does not vary with speed regardless of the spring stiffness used. This result may be attained by making  $\partial C_{he}/\partial \alpha_T$  and  $\partial C_{ht}/\partial \alpha_T$  equal to zero and by using a tab-gearing ratio such that the force per g at low speed is reduced to the value which would be obtained at very high speed, where the characteristics of a servotab are approached. In practice, it is unlikely that the exact values of hinge-moment characteristics required could be obtained. Some variation of force per g with speed would result if these characteristics

differed slightly from the desired ones. The variation of force per g with speed would be smaller, however, than that obtained with an ungeared spring tab with the same spring stiffness. It therefore appears that the stick-force characteristics shown in figures 3 to 6 could be improved by the use of geared spring tabs. Stiffer springs, providing improved ground control, could be used alternatively for the same variation of force per g with speed. Errors in obtaining the desired value of  $\partial C_{He} / \partial \delta_e$  for the geared spring tab may be compensated by adjustment of the tab linkage by trial on the actual airplane.

Preloaded spring tab.- If the tab spring is preloaded to prevent deflection of the tab until the stick force exceeds a certain amount, the stick force per g will equal that of the elevator without a spring tab up to the point where the stick force reaches the preload. Beyond this point, the force per g will equal the force calculated for an unpreloaded spring tab. The force variation with acceleration will therefore be nonlinear, a characteristic usually considered to be undesirable.

If friction is present in the tab system, an unpreloaded spring tab may not return to a definite equilibrium position and, as a result, the pilot may experience difficulty in maintaining a specified trim speed. A small amount of preload may be used to center definitely the tab in trimmed flight and thereby to overcome this difficulty. In view of the mechanical complications involved in the use of a preloaded spring, as well as the nonlinear force characteristics mentioned previously, it appears desirable to avoid the necessity for preload by reducing friction in the tab system to a minimum.

## CONCLUSIONS

An analysis of the effects of spring tabs on elevator forces for airplanes of various sizes has indicated the following conclusions:

1. By the use of spring tabs, satisfactory elevator control-force characteristics may be obtained over a large center-of-gravity range on airplanes varying in weight from about 16,000 to at least 300,000 pounds.

2. The spring tab offers the possibility of greatly reducing the changes in stick forces that result from small variations in contours of the elevators on different airplanes of the same type.

3. The elevator control-force characteristics resulting from the use of a spring tab should be more closely predictable than those with other types of aerodynamic balance such as a balancing tab or inset-hinge balance; in order to take advantage of this effect, however, more complete information on the hinge-moment characteristics of tabs is required.

4. One of the chief objections to the use of spring tabs is the amount of weight required for mass balance to prevent flutter. Experimental work is recommended in order to find means of reducing the amount of balance weight required.



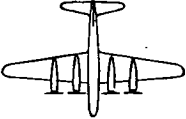
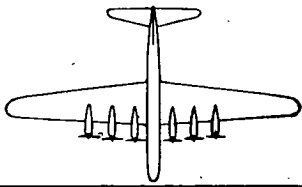
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TABLE I.- CHARACTERISTICS OF VARIOUS AIRPLANES

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	Scout bomber	Medium bomber	Heavy bomber	300,000-pound airplane
				
Scale, ft	0 50	0 100	0 100	0 100 200
W, lb	16,000	50,000	125,000	300,000
b, ft	49	89.5	143	223.5
S, sq ft	400	1000	2275	5000
c, ft	8.16	11.18	15.90	22.35
l, ft	20	35	50	75
S <sub>T</sub> , sq ft	100	200	455	1000
$\left(\frac{\partial C_L}{\partial \alpha}\right)_W$ , per radian	4.2	4.5	4.6	4.7
$1 - \frac{d\epsilon}{d\alpha}$	0.5	0.55	0.57	0.60
q <sub>T</sub> /q	1.0	1.0	1.0	1.0
b <sub>e</sub> , ft	20	34	50	75
c <sub>e</sub> , ft	1.8	2.2	3.2	4.8
b <sub>t</sub> , ft	5.0	7.35	15.0	26.2
c <sub>t</sub> , ft	0.50	0.80	0.60	0.666
r	0.5	0.5	0.5	0.5
$\frac{\partial C_{L_T}}{\partial \delta_e}$ , per radian	1.7	1.7	1.7	1.7
I, slug-ft <sup>2</sup>	0.5	1.5	7.0	35
K <sub>1</sub> , ft per radian	1.80	1.80	1.80	1.80
K <sub>2</sub> , ft per radian	-0.60	-0.45	-1.20	-1.20
K <sub>3</sub> , lb per radian	33.3	100	124	200
$\frac{\partial C_{h_g}}{\partial \alpha_T}$ , per deg	0	0	0	0
$\frac{\partial C_{h_g}}{\partial \delta_e}$ , per deg	-0.003	-0.003	-0.003	-0.002
$\frac{\partial C_{h_g}}{\partial \delta_t}$ , per deg	-0.003	-0.003	-0.003	-0.003
$\frac{\partial C_{h_t}}{\partial \alpha_T}$ , per deg	0	0	0	0
$\frac{\partial C_{h_t}}{\partial \delta_e}$ , per deg	0	0	0	0
$\frac{\partial C_{h_t}}{\partial \delta_t}$ , per deg	-0.005	-0.005	-0.005	-0.003



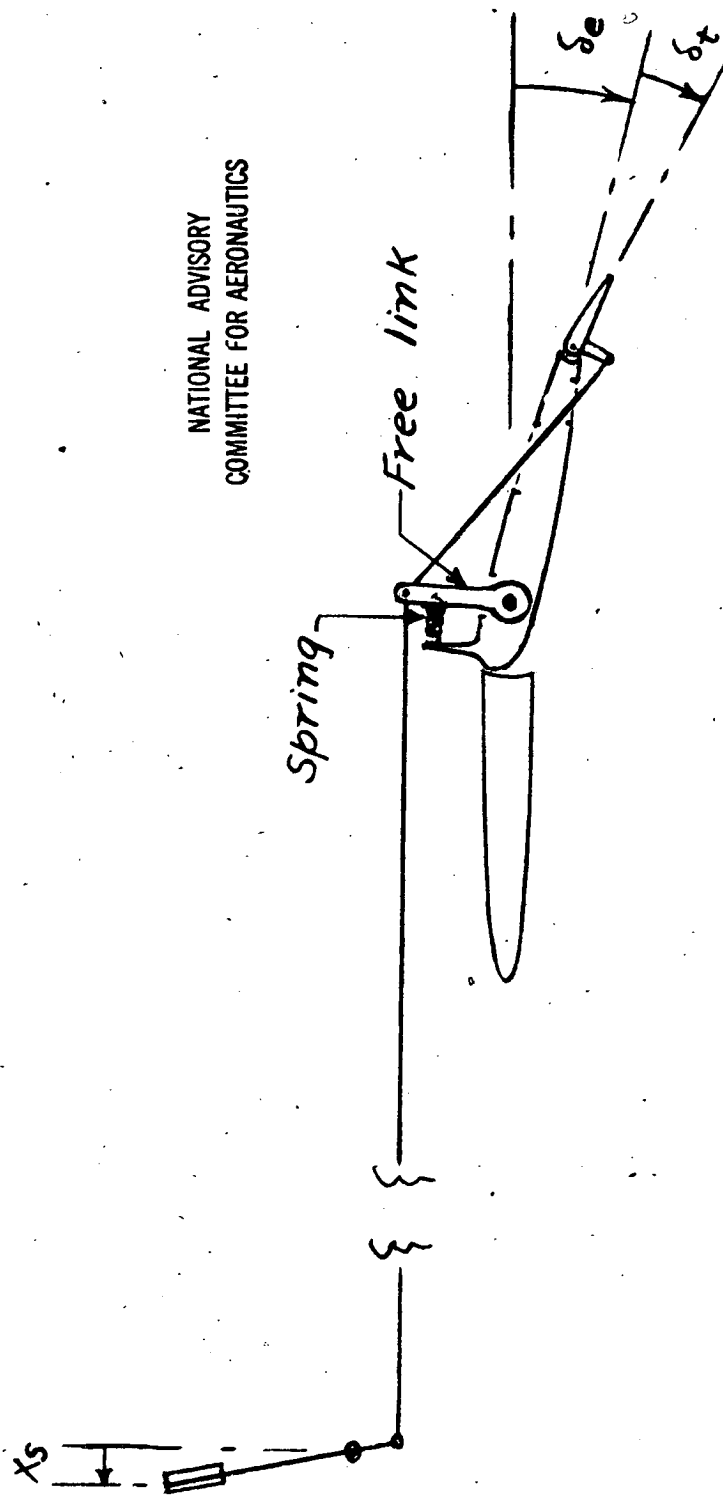


Figure 1.- Spring-tab arrangement considered in calculations.

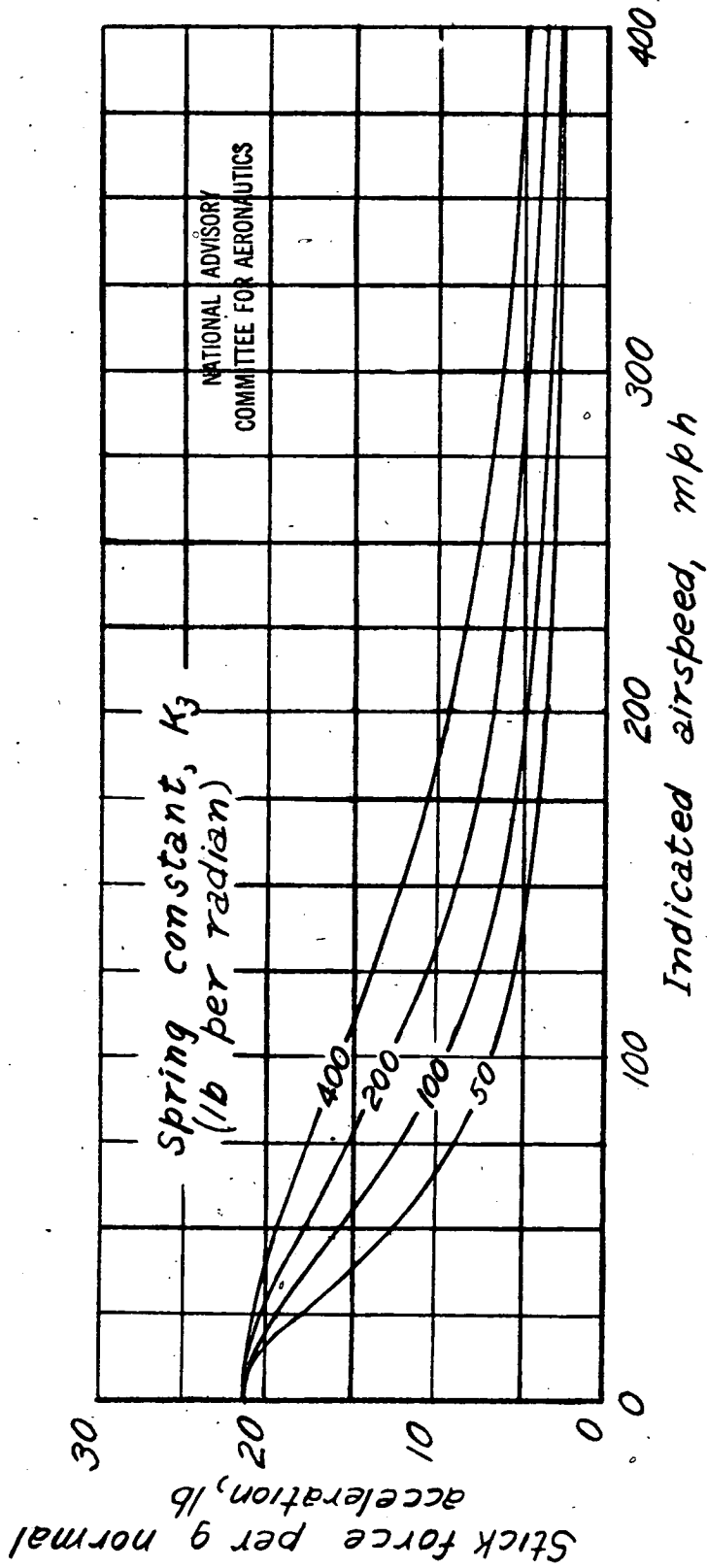


Figure 2.- Variation of force per g normal acceleration with speed for typical spring-tab installation with various amounts of spring stiffness. (Values of force per g below stalling speed have no physical significance.)

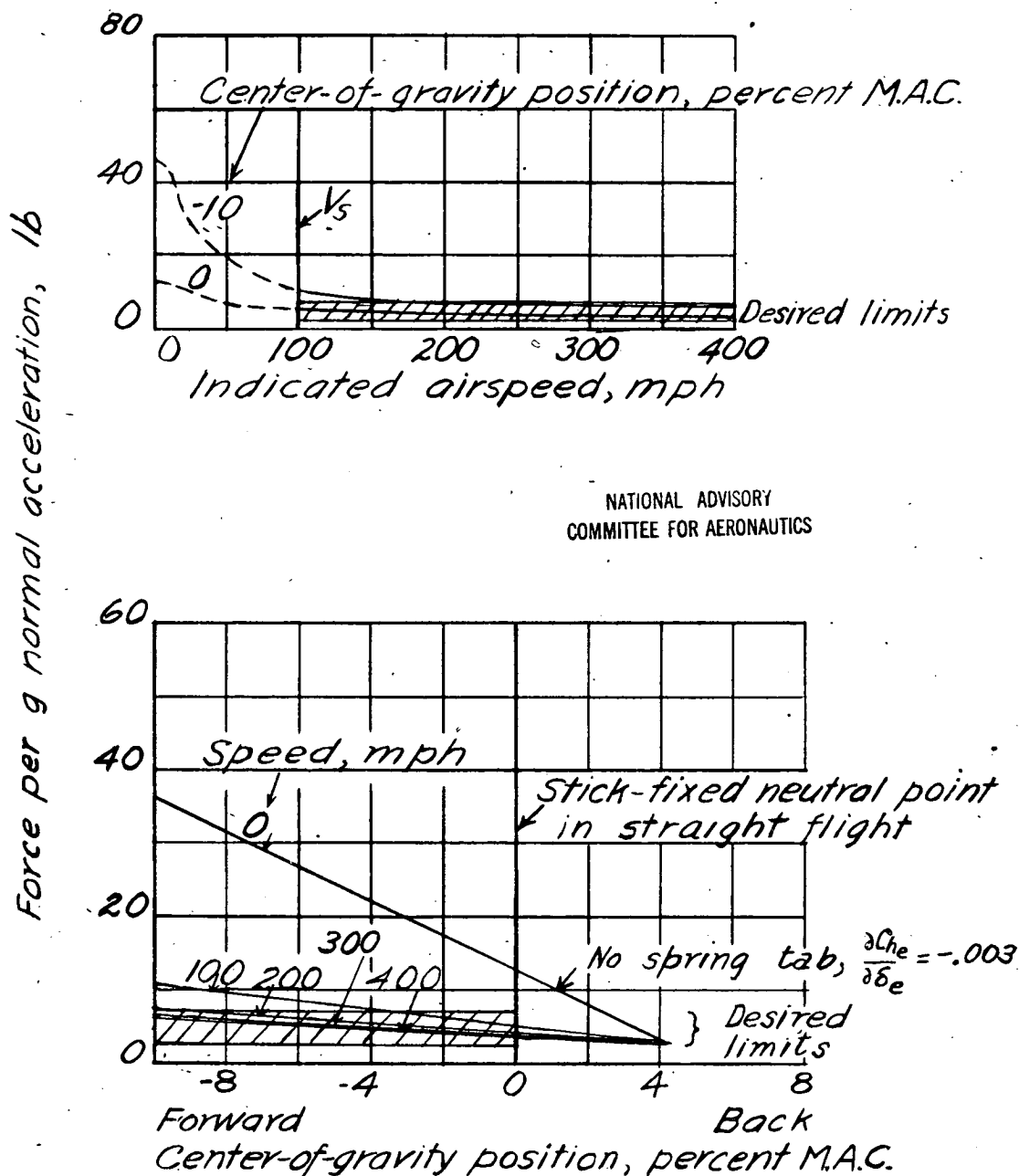


Figure 3.- Variation of force per g with speed and with center-of-gravity position for scout bomber (weight, 16,000 lb).

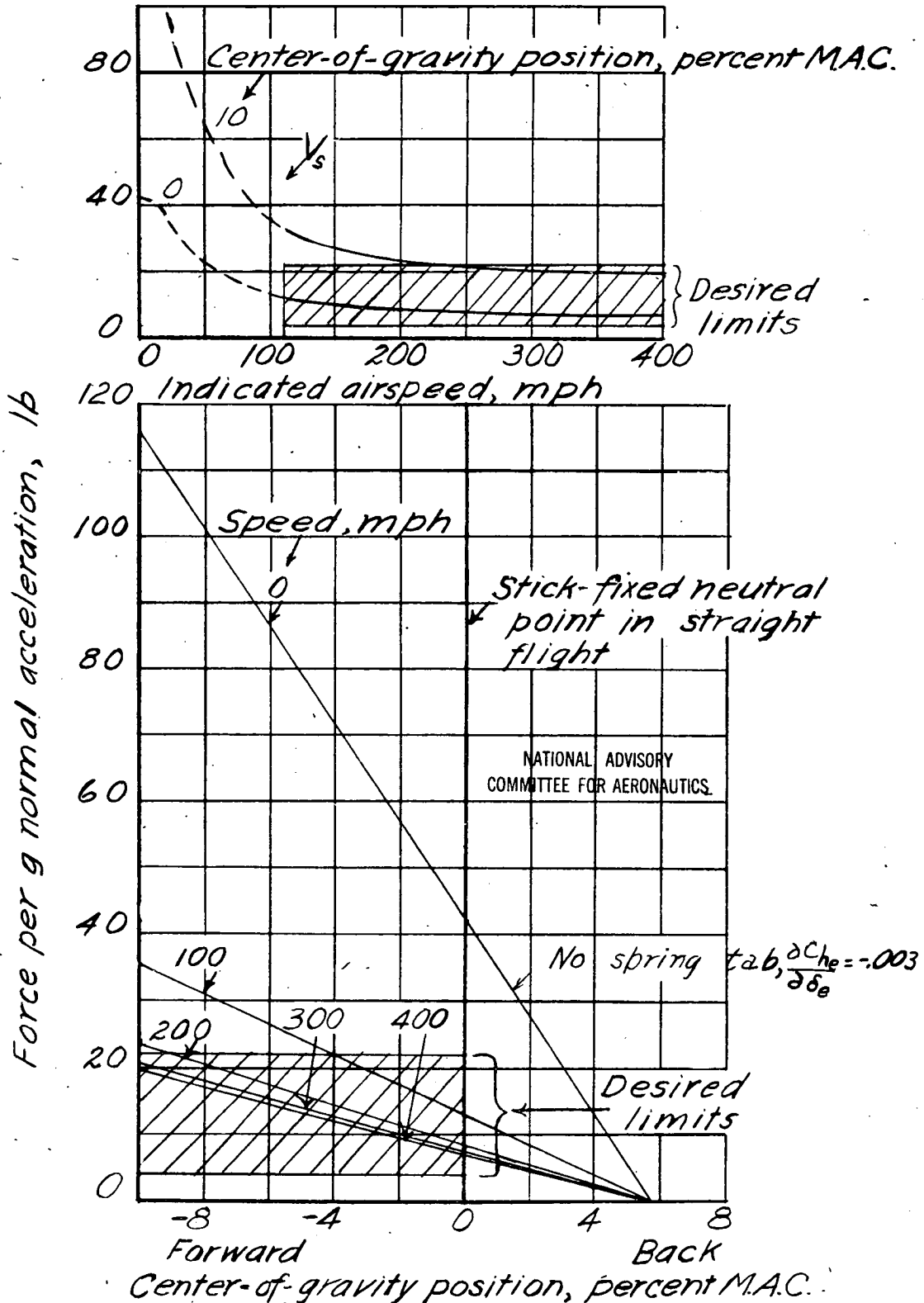


Figure 4.- Variation of force per g with speed and with center-of-gravity position for medium bomber (weight, 50,000 lb).

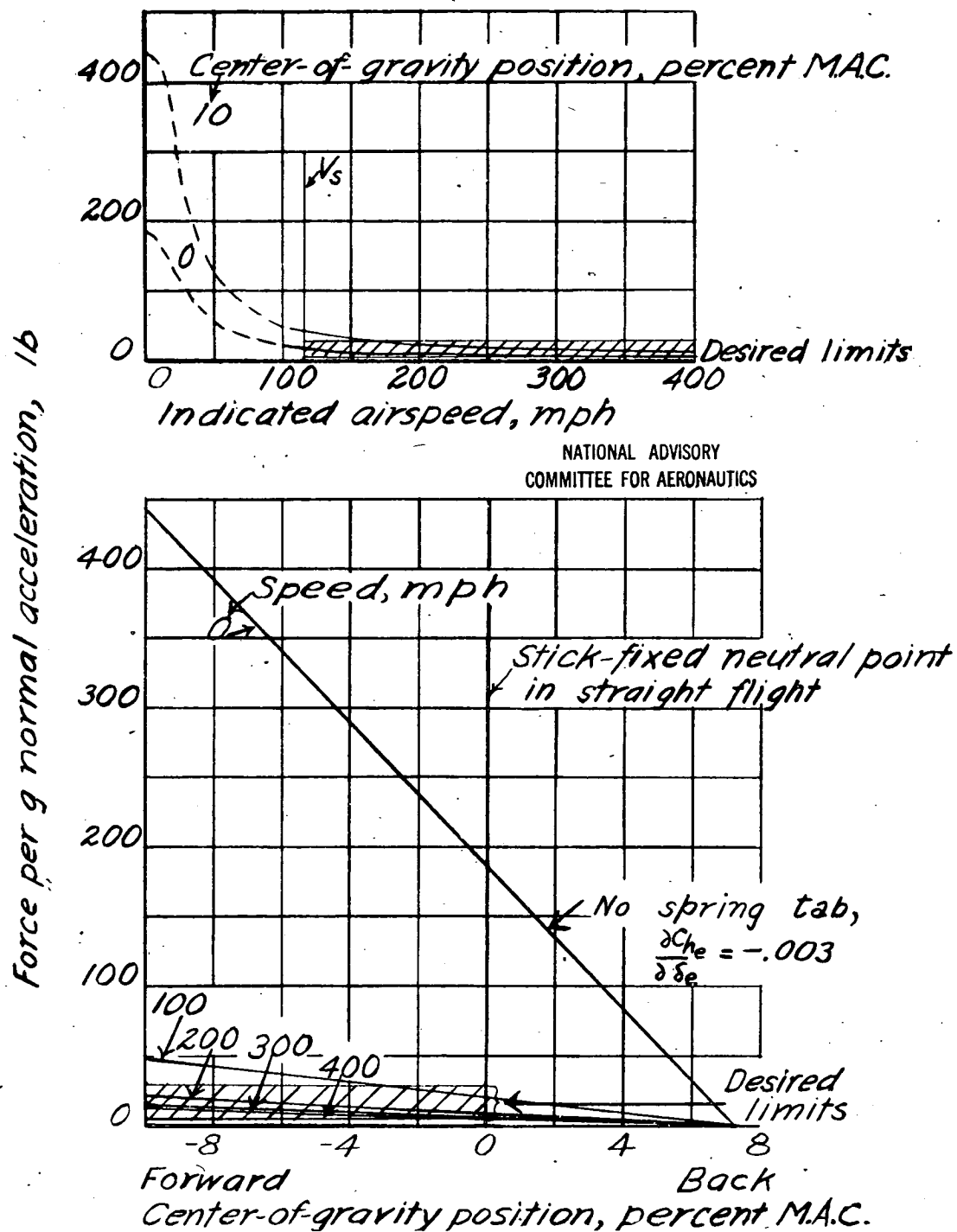


Figure 5.- Variation of force per g with speed and with center-of-gravity position for heavy bomber (weight, 125,000 lb).

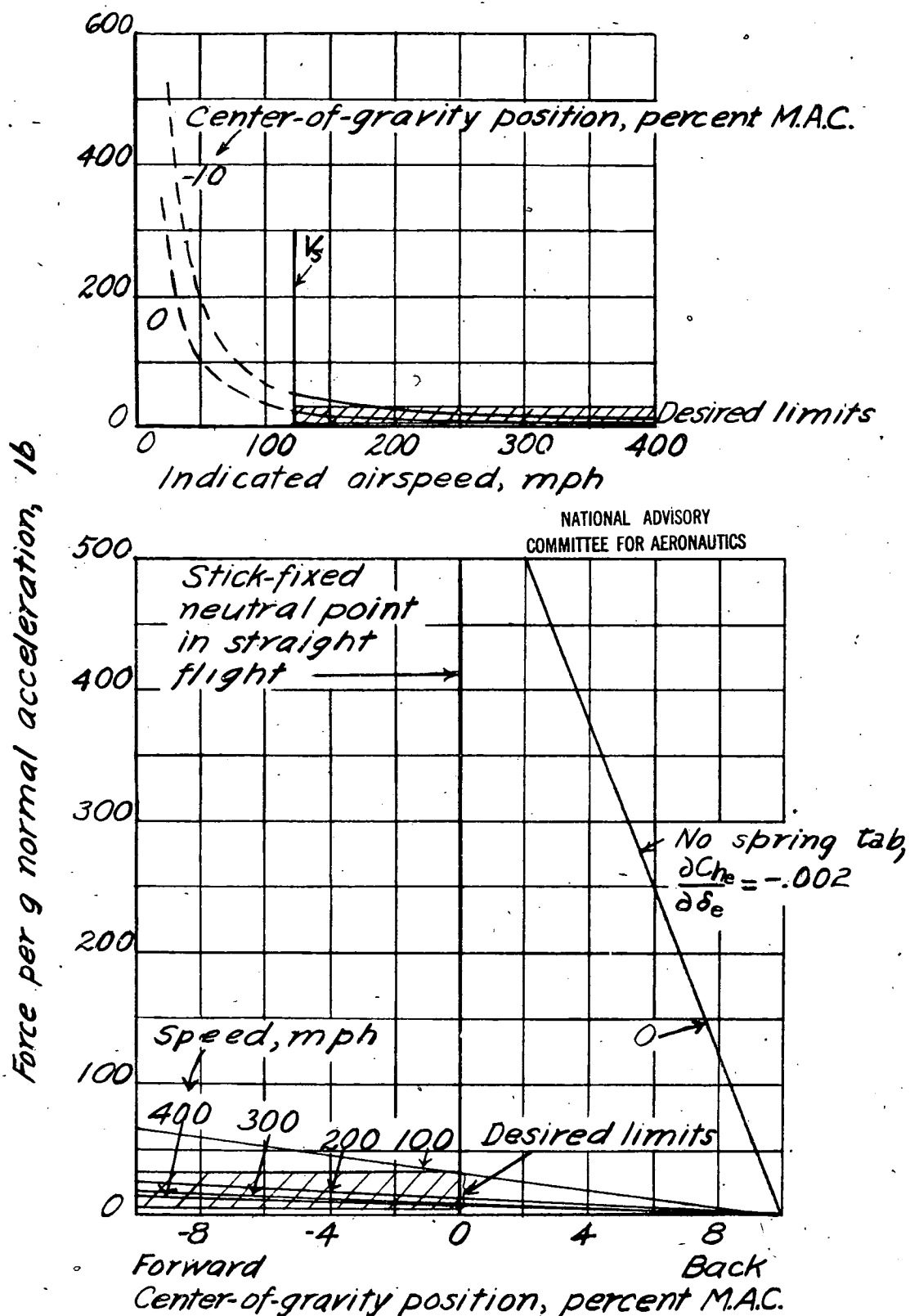
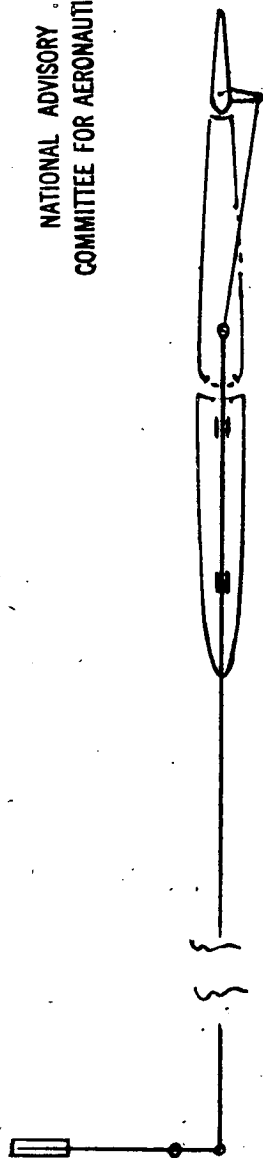
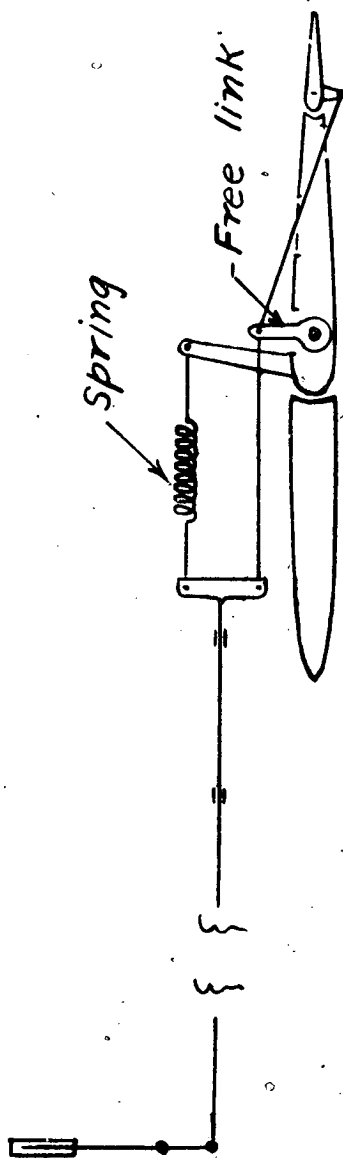


Figure 6.- Variation of force per g with speed and with center-of-gravity position for 300,000-pound airplane.

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(a) Tab controlled independently of elevator.



(b) Geared spring tab.

Figure 7.- Special spring-tab arrangements.